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A STUDY ON THE EFFICIENCY OF THE MARKET FOR DUTCH LONG TERM CALL OPTIONS

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A STUDY ON THE EFFICIENCY OF THE MARKET FOR DUTCH LONG TERM CALL OPTIONS

Abstract

We investigate the efficiency of the market for 5 year call options which are traded on the European Options Exchange in Amsterdam. We study both delta, delta-vega, and delta-gamma neutral arbitrage portfolios. We do not detect any serious inefficiencies in the market for long term call options. This result is in line with previous studies on different kinds of call options and warrants. The results for the delta-vega and delta-gamma neutral arbitrage strategies differ from the results of the simple delta-neutral strategies in two ways: they lead to positive results more often, but the variance of these results is also larger.

1. Introduction

In this paper we study the efficiency of the market for Dutch long term call options. These call options, which have an initial maturity of 5 years, were introduced in October 1986 on the European Options Exchange (EOE) in Amsterdam. They are contingent on the shares of five large Dutch multinationals (Akzo, KLM, Philips, Royal Dutch, and Unilever). At the time of the introduction, these options were unique, because call options traded on other option exchanges had a maximum maturity of only 9 months[1]. Despite their uniqueness until now only little empirical research has been published with regard to the Dutch long term call options. Veld and Verboven (1995) have compared the prices of these call options with the prices of equity warrants contingent on the same stock. After comparing implied standard deviations of the call options and the warrants they concluded that the warrants are (to a large extent) overvalued relative to the long term call options. In this paper we will test the efficiency of the market for Dutch long term call options (from now on DLTCs). We will do this by studying the possibility to acquire arbitrage profits by creating positions with DLTCs contingent on the same stock, but with different exercise prices and maturities, which are neutral with respect to several risk factors.

The methodology we use is based on the standard methodology for testing option market efficiency. The first study in this field was carried out by Black and Scholes (1972). They tried to create a risk free position by buying (selling) options that were undervalued (overvalued) relative to their model and shorting (buying) delta shares of the underlying stock. They tested whether the return on this position was larger than the risk free rate of return. In their study this proved to be the case, thereby indicating inefficiencies on the over-the-counter market. However, when transaction costs were taken into account, possible arbitrage profits quickly disappeared. Galai (1977) repeated the Black-Scholes tests for the Chicago Board of Options Exchange (CBOE). He first carried out an ex post test. This test was performed under the assumption that trading at the closing price on day t, based on a trading rule that was decided by the same price, was possible. Galai (1977) found significant positive arbitrage profits. However, these arbitrage profits disappeared

[1] In 1990 the Chicago Board of Options Exchange (CBOE) also introduced call options with a maximum initial maturity of 3 years. They are often referred to as LEAPS (Long-term Equity-Anticipation Securities), see Johnson and Giaccotto (1995, page 527).

when a 1% transaction cost was imposed. In an ex ante test, the execution of trading was delayed by one day. On day t it was decided whether the option was over- or undervalued and the hedge ratio was calculated. The hedge was established on day t+1 and liquidated on day t+2. In this test he also found arbitrage profits, but these were significantly lower than in the ex post test. The ex ante profits also disappeared when transaction costs were considered. Galai (1977) was also the first to suggest a spreading strategy. This strategy consists of a long position in one option and a short position in another option on the same underlying stock. Galai's spreading results were in line with his earlier mentioned results[2].

In a paper from 1985 Chen and Johnson argued that, given that the market price deviates from the model price, the Black-Scholes technique only produces a riskless hedge if the options are held until maturity. If the option position is to be revised more frequently, an alternative hedge ratio has to be used. Such an alternative hedge ratio is derived in their paper. Lauterbach and Schultz (1991) who study the efficiency of the US market for equity warrants, use both the Black-Scholes and the Chen-Johnson hedge ratios in order to create riskless stock-warrant hedges. They find positive abnormal returns for an ex post strategy and lower, but still positive, abnormal returns, for an ex ante strategy. They find that the results for the Black-Scholes and the Chen-Johnson hedge ratios are roughly the same. When making corrections for transaction costs they conclude that only floor traders are able to make arbitrage profits. These results are important for this research, because Lauterbach and Schultz (1991) study equity warrants which, like DLTCs, have long maturities. Finally, Wei (1994) who studies Nikkei Put Warrants, also finds that the market for these long term contracts is efficient if ex ante tests and transaction costs are considered.

All the above mentioned studies limit themselves to delta neutral hedges. However, a delta neutral portfolio is not entirely risk free. For a portfolio to be really risk free, the change of the value of the portfolio should be immune with regard to the underlying asset's volatility (vega), the delta (gamma), the passage of time (theta), and the riskless interest

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[2] Other studies on options market efficiency were carried out by Chiras and Manaster (1978) and Blomeyer and Klemkosky (1983). Phillips and Smith (1980) present a correction for transaction costs on the results of Chiras and Manaster (1978). See Galai (1983) for a review of a number of efficiency studies.

rate (rho). In this paper we will limit ourselves to delta-vega and delta-gamma neutral hedges. The reason is that, after a portfolio is delta neutral, its vega and gamma are considered to be most important (see Hull, 1993, page 298)[3]. The analysis in this paper can easily be extended to e.g. delta-theta, delta-rho, delta-gamma-vega hedges, and so on.

The most important empirical findings in this paper can be summarized as follows. The delta neutral trading strategy gives results which are in line with the results in related literature. Positive arbitrage profits can be found for ex post strategies without transaction costs. However, the profits disappear when transaction costs and/or ex ante hedges are considered. The results for delta-gamma and delta-vega neutral strategies do not deviate much from the results of the delta neutral strategy. The delta-gamma and delta-vega neutral strategies lead more often to positive results. However, the profits also seem to be more variable. Therefore we can not detect any serious inefficiencies in the market for DLTCs.

The remainder of this paper is organized as follows. In section 2 the methodology and data description are presented. Our main results are presented in section 3. The paper is concluded in section 4 in which a summary and some conclusions are presented.

2. Methodology and data description

2.1. Data description

In this study we use daily closing prices of long term call options for the period of April 1 to September 30 for the years 1990 and 1991. For each stock, each year in October one new series of call options is introduced with an exercise price close to the then prevailing stock price. Trading in long term call options started in 1986. Therefore in October 1991 the first series expired. In appendix 1 the long term call options outstanding in our research period (with their respective exercise prices, introduction months, and expiration dates) are presented. In our research we do not use all the available series, since we always have four options series while at most three are needed for our hedging strategies.

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[3] Clewlow et. al. (1995) also discuss the use of delta-vega and delta-gamma hedges in a different context. See also Fung (1995) for a comment on their analysis. Clewlow et al. and Fung use the term kappa instead of vega.

Although the interest here is in long term call options, we do not want to loose too many observations because of liquidity problems. Therefore, we always combine one or two long term options with the shortest-to-maturity options which are the most actively traded. In the delta neutral trading strategy we use the longest-to-maturity and the shortest-to-maturity options. In the delta-gamma and delta-vega neutral trading strategies we use the shortest-to-maturity and the two longest-to-maturity options. Because we want to focus on *long* term call options, we define the shortest-to-maturity option as the option with a maturity between 1 and 2 years. Therefore, in 1990 we use the 1986 series and in 1991 we use the 1987 series as the shortest-to-maturity options. The longest-to-maturity options in 1990 and 1991 are respectively the 1988 and 1989 series and the 1989 and 1990 series.

In table 1 the number of long term call options investigated in each year is included. If on a certain day there is no trading in an option and/or if the price of the option is less than its intrinsic value, the observation is excluded from the sample.

[Insert Table 1]

Information on the call option prices, the prices of the underlying stock, the exercise prices, and the maturities, is derived from Datastream. The only exception are the call option prices of the series issued in 1986. At the time we started this research these series were no longer available in Datastream, therefore this information had to be taken from the Dutch financial newspaper "De Officiële Prijscourant", an official publication of the stock and options exchanges in Amsterdam. The riskless interest rate used to calculate the model prices of the options, is estimated as the yield on government bonds with a maturity of 3 to 5 years, which is also derived from "De Officiële Prijscourant".

For the period from April 1 to September 30 in year t the dividend yield is taken to be the ratio of the dividend paid in the period April 1 of year t-1 to March 31 of year t, over the average stock price in that period, which was estimated as the average of the closing stock prices realized on the first trading day of each month.

In this study we investigate whether arbitrage possibilities exist if the model price of option i ($C^{mod}_{i,t}$) differs from its market price ($C^{mkt}_{i,t}$). We calculate model prices using the binomial tree of Cox, Ross, and Rubinstein (1979). By doing this we assume that the model of Black and Scholes (1973) for the stock price process holds and taking into account dividend payments and early exercise possibilities.

As a measure of the volatility we use the average of the implied volatilities of each option over the last three trading days. This measure avoids the calculated option prices to depend on one estimated volatility only, which might cause spurious arbitrage profits. At the same time our measure still uses the most recent information in the market.

2.2. Methodology

Delta hedges

In this paper we use the spreading strategy as originally suggested by Galai (1977). We start by using simple delta-neutral trading strategies. The relative mispricing between DLTCs A and B can be detected by comparing the ratio of model prices with the ratio of market prices. These ratios are based on the closing prices of the stock and the options. More precisely, the methodology is as follows. If:

$$\frac{C_{A,t}^{mod}}{C_{B,t}^{mod}} > \frac{C_{A,t}^{mkt}}{C_{B,t}^{mkt}}$$

then we buy DLTC A and sell B. In order to make the trading strategy neutral in delta, we take a long position of 1 contract in option A and a short position of Δ_A/Δ_B contracts in option B. Here Δ_i is the delta of option i. If the relationship between the ratios is the reverse, we sell one contract DLTC A and buy Δ_A/Δ_B contracts B.

The efficiency of the market for DLTCs is analyzed using both an ex post and an ex ante strategy. In the *ex post* strategy the mispricing is observed using the closing prices at day t and the portfolio of options is established at these same prices. The portfolio is liquidated at the market prices on day t+1. In the *ex ante* strategy the mispricing is observed using the closing prices at day t, after which a portfolio is established at day t+1. The portfolio is then liquidated at the market closing prices on day t+2.

Both the *ex post* and the *ex ante* strategy are carried out with and without transaction costs. In case transaction costs are taken into account we assume a fixed one-way trading cost of *f* 1.00 per option contract (one contract is 100 options)[4]. Thus, in total we

[4] In theory we should also have included interest expenses and incomes when calculating daily profits. However, the interest expenses/incomes are very small on a daily

distinguish 4 different delta-neutral trading strategies.

This procedure will be carried out for the two sample periods. We use for options A and B the longest-to-maturity and the shortest-to-maturity options respectively. Thus, for the 1990 sample, we use the series issued in 1986 and 1989, and for the 1991 sample we use the series issued in 1987 and 1990. This gives a total of 40 time series of profits.

As Chen and Johnson (1985) point out, given that we create an option portfolio using options which are mispriced relative to the Black and Scholes model, using the Black-Scholes hedge ratio does not create a riskless position and because of this the results of the tests may be biased. Chen and Johnson (1985) show how a modified hedge ratio can be calculated which takes into account the fact that the option is mispriced. To correct for the inconsistency of using the Black-Scholes hedge ratio, we also investigate the above mentioned strategies using the modified deltas as in Chen and Johnson.

Delta-gamma and delta-vega hedges

A portfolio which is delta-neutral will not be entirely risk free if there is also uncertainty with respect to other factors, such as the underlying asset's volatility, the option delta, or the interest rate. Therefore, if any of these factors are important, the portfolio should also be made neutral in vega, in gamma and in rho which measure the option sensitivity with respect to the asset's volatility, the option delta, and the interest rate respectively.

If we study the efficiency of an option market with a delta-neutral trading strategy, we may come to a false conclusion if the delta-neutral portfolios are not risk free. First, we may conclude that the market is inefficient because a delta-neutral trading strategy leads to positive profits which in reality are normal rewards for the risk of our portfolio. Second, we may conclude that the market is efficient because the delta-neutral trading strategy earns zero returns, while the truth is that a negative return would be appropriate given the risk of the portfolio[5].

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basis, also in relation to the profits on the hedge portfolios. Therefore we will simply ignore the interest effects. Note also that for a given arbitrage portfolio, the total cash position can be positive or negative. Therefore, the total effects of borrowing and lending can be self canceling over time (see Wei, 1994).

[5] This latter situation may occur for instance if the short positions in the call options result in a portfolio with a negative beta.

As argued by Hull (1993, page 298), once a portfolio is neutral in delta, then vega and gamma can be considered to be most important. Therefore, besides trading strategies which are neutral in delta only, we will also consider strategies which are neutral in delta and vega and in delta and gamma[6].

To illustrate, consider a delta-gamma neutral trading strategy. In general, in order for an option portfolio to be neutral in 2 factors we need three option positions:

$$P_t = \lambda_{A,t}C_{A,t} + \lambda_{B,t}C_{B,t} + \lambda_{C,t}C_{C,t}, \tag{1}$$

where P_t is the value of the portfolio at time t and $\lambda_{i,t}$ is the position taken in option i. Normalizing $\lambda_{A,t}$ to 1, it is straightforward to show that in order for the portfolio in (1) to be neutral in delta and gamma, $\lambda_{B,t}$ and $\lambda_{C,t}$ have to be chosen as:

$$\lambda_{B,t} = \frac{\Delta_{A,t}\Gamma_{C,t} - \Delta_{C,t}\Gamma_{A,t}}{\Delta_{C,t}\Gamma_{B,t} - \Delta_{B,t}\Gamma_{C,t}} , \quad \lambda_{C,t} = \frac{\Delta_{B,t}\Gamma_{A,t} - \Delta_{A,t}\Gamma_{B,t}}{\Delta_{C,t}\Gamma_{B,t} - \Delta_{B,t}\Gamma_{C,t}} . \tag{2}$$

The trading strategy investigated here involves finding triplets of options A, B, and C, for which option A is priced too high relative to option B and for which option B is priced too high relative to option C, while at the same time $\lambda_{C,t} > \lambda_{B,t} > \lambda_{A,t}$. Thus we look for triplets of options such that:

$$\frac{C_{A,t}^{mkt}}{C_{B,t}^{mkt}} > \frac{C_{A,t}^{\text{mod}}}{C_{B,t}^{\text{mod}}} , \quad \frac{C_{B,t}^{mkt}}{C_{C,t}^{mkt}} > \frac{C_{B,t}^{\text{mod}}}{C_{C,t}^{\text{mod}}} , \quad \text{and} \quad \lambda_{A,t} < \lambda_{B,t} < \lambda_{C,t} . \tag{3}$$

We start by assigning the longest-to-maturity option as option A, the second longest-to-maturity option as option B, and the shortest-to-maturity option as option C. If the ordering obtained with these options does not fulfil the requirement in (3) then the second longest-to-maturity option is assigned as option A, the longest-to-maturity option is assigned as option B, and the shortest-to-maturity option is assigned as option C. This strategy makes sure that we always have the largest position in the option that is relatively cheapest, while we have the smallest position in the most expensive option.

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[6] Vega neutrality is more important for long term call options, while gamma neutrality is more important for short term call options.

As with the delta-neutral trading strategy, both an *ex post* and an *ex ante* strategy are investigated. Also, the strategies are analyzed with zero transaction costs and with one-way transaction costs of *f* 1.00 per contract, implying that we have 4 different delta-gamma neutral trading strategies.

Trading strategies which are neutral in delta and vega are investigated in a completely analogous way as the trading strategies which are neutral in delta and gamma which we just described. The only difference is of course that in (2) $\Gamma_{i,t}$ should be replaced by $\Lambda_{i,t}$. Here also, we investigate *ex post* as well as *ex ante* strategies and we take the case where transaction costs are zero and where there are one-way transaction costs of *f* 1.00 per contract.

Applying the same reasoning as in case of the delta-neutral trading strategies, the strategies described here will not be risk free if the Black-Scholes hedge ratios are used, given that the options are mispriced relative to the Black and Scholes model. Therefore, we also investigate the delta-gamma and delta-vega neutral trading strategies using the modified hedge ratios as suggested by Chen and Johnson (1985). Since the modified Chen-Johnson hedge ratios sometimes lead to large option positions, thereby causing outliers, we restrict both $\lambda_{A,t}$ and $\lambda_{B,t}$ to be no larger than 10. In other words, we assume that traders will not use more than 10 option contracts to hedge a position in one other option contract.

3. Results

In order to analyze the efficiency of the market for DLTCs, the median and average profits are calculated for each strategy, as well as the concomitant standard deviations. The autocorrelations of the daily profits, which are not reported here[7], are always quite small and do not impose any problem for the calculated standard errors.

Delta-neutral trading strategies

In table 2 we present the results for the delta-neutral trading strategies when the Black-

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[7]These autocorrelations, as well as other additional summary statistics on the results from our hedging strategies, are available on request from the authors.

Scholes hedge ratios are used. Table 3 presents the same results in case the modified hedge ratios as in Chen and Johnson (1985) are used.

[Insert Tables 2 and 3]

The first two columns in table 2 present the guilder profits for an ex post delta-neutral trading strategy, in case there are zero transaction costs. This situation can be considered to be a benchmark, representing the profits which a trader could have made if he did not have to pay any transaction costs and if he could trade immediately at the observed market prices. Such a trader could have made average profits which are significantly larger than zero in 5 out of the 10 series which are investigated. Also, only in 2 out of the 10 series the average profit is (not significantly) smaller than zero. Moreover, these losses are small relative to the profits in the other series.

The second series of two columns in table 2 show that once a trader has to pay one-way transaction costs of ƒ 1.00 per contract, he would have made an average profit which is significantly larger than zero in only 2 out of the 10 series. However, only 3 of the series have average profits (not significantly) smaller than zero.

From the last four columns in table 2 we can conclude that the supposed arbitrage opportunities disappear within one day. When an ex ante strategy is used there is no average trading profit significantly larger than zero either with or without transaction costs. When transaction costs are zero only in 3 series would a trader have made positive average profits, while with one-way transaction costs of ƒ 1.00 per contract all but one of the average profits are negative.

These results do not change much when the Chen-Johnson hedge ratios are used. The results in table 3 only show small differences from the results in table 2, except for the ex post results of the Akzo options in 1991, which is caused by one big profit which disappears with the Chen-Johnson ratios. There is no systematic difference between the results based on the Black-Scholes hedge ratios and the results based on the Chen-Johnson hedge ratios.

If the profits made with a delta-neutral trading strategy are risk free then tables 2 and 3 suggest that the Dutch market for long term call options is efficient. Although half of the series show an average profit which is significantly larger than zero, most of these profits disappear once transaction costs are introduced. Moreover, there are no significant profits in an ex ante strategy, in which a trader has to wait one day before he can trade on the basis of observed mispricings.

Delta-vega neutral trading strategies

The results of a trading strategy that is neutral in both delta and vega, i.e. which controls both for the uncertainty in the price of the underlying and its volatility, are presented in table 4 for the Black-Scholes hedge ratios and in table 5 for the Chen-Johnson hedge ratios.

[Insert Tables 4 and 5]

For the ex post strategies the results in table 4 are clearly very similar to the results of the delta-neutral trading strategies in table 2. In table 4 we find that without transaction costs 4 out the 9 series show an average profit significantly larger than zero. After the introduction of one-way transaction costs of ƒ 1.00 per contract only one of these remains, while only 3 of the 9 series show losses.

With the ex ante strategies all these significant profit opportunities disappear as was the case with the delta-neutral trading strategies. However, with the delta-vega neutral trading strategies the average profits are more often positive than with the trading strategies which are only neutral in delta. When there are no transaction costs, the ex ante average profits in table 4 are positive in 6 out of 9 series, and with transactions they are positive in 5 out of 9 series. However, given that the variation within the observed series is of the same order of magnitude as the variation between the series, and that the variation of the profits appears to be somewhat larger for the delta-vega neutral trading strategies relative to the delta-neutral trading strategies, we can not conclude that the delta-vega hedges are superior to the delta-hedges.

In slight contrast to the results in tables 2 and 3, the results in tables 4 and 5 indicate that now it does matter whether we use Chen-Johnson hedge ratios or Black-Scholes hedge ratios. The pattern of the results is the same for table 5 as for table 4, in that an ex post strategy shows a nontrivial number of significant profits, which disappear in the ex ante strategy and/or when transaction costs are taken into account. For individual series the differences between using the Black-Scholes hedge ratios and the Chen-Johnson hedge ratios are now somewhat more apparent than for the delta-neutral trading strategies in tables 2 and 3, although tables 4 and 5 appear to be roughly in line with each other. Once again, there does not seem to be any pattern in the differences that arises from the use of these different hedge ratios.

Overall, the conclusion that we can derive for the delta-vega neutral trading strategy is the same as the conclusion from the delta-neutral trading strategy. The Dutch market for long term call options does not show any serious inefficiencies. Any supposed arbitrage profits in an ex post strategy quickly disappear once transaction costs are taken into account and once we use an ex ante strategy. Compared to the delta-neutral trading strategy there are now somewhat larger differences between using the Black-Scholes hedge ratios and using the Chen-Johnson hedge ratios. Also, the profits of the ex ante strategy seem to be positive more often in the delta-vega neutral strategies than in the delta-neutral strategies, but the profits in the delta-vega neutral strategies also seem to be more variable. This may indicate that controlling for both the uncertainty in the price of the underlying and its volatility does not add much beyond controlling for only price uncertainty in this kind of trading strategies.

Delta-gamma neutral trading strategies

A trading strategy that is neutral in both delta and gamma takes into account that the option portfolio is not only sensitive to changes in the price of the underlying but also to changes in the deltas. In other words, a delta-gamma neutral strategy takes into account nonlinearities in the hedge portfolio return as a function of the price of the underlying. The results of such a strategy are presented in table 6 for the Black-Scholes hedge ratios and in table 7 for the Chen-Johnson hedge ratios.

[Insert Tables 6 and 7]

In table 6 we can observe that for the ex post strategy with no transaction costs 6 out 9 average profits are significantly larger than zero, while there is only one loss. After introducing transaction costs still 3 out of 9 average profits are significantly larger than zero and only 2 average losses occur.

When there are no transaction costs even the ex ante strategy in table 6 still shows one average profit which is significantly larger than zero. Once a one-way transaction cost of ƒ 1.00 per contract is taken into account, this profit disappears as well. As with the delta-vega neutral strategy the number of losses in the delta-gamma neutral strategy is smaller than in the delta-neutral strategy of table 2. However, here also the variability of the profits seems to be rather large both within and between the observed series.

Also as in the delta-vega neutral trading strategies, the differences between using the Black-Scholes hedge ratios and the Chen-Johnson hedge ratios are larger than for the delta-neutral trading strategies, but the results in tables 6 and 7 still seem to be roughly in line with each other, Note however, that the number of significant profits in table 7 is much smaller than in table 6.

The general conclusion that can be derived from tables 6 and 7 is once again that the option market studied in this paper does not show any serious inefficiencies. Analogous to the delta-neutral and delta-vega neutral trading strategy, any perceived ex post arbitrage possibility disappears when a more appropriate ex ante strategy is used and when transaction costs are taken into account. Also, as in case of controlling for volatility risk, making a trading strategy neutral in both delta and gamma does not add much to the trading strategies which are neutral in delta only.

4. Summary and conclusions

In this study we have investigated the efficiency of the market for Dutch long term call options (DLTCs). We have studied delta, delta-vega and delta-gamma neutral trading strategies. With regard to the delta neutral trading strategy we find arbitrage profits for ex post strategies without transaction costs. However, these profits disappear when transaction costs and/or ex ante trading strategies are considered. Results for the Chen-Johnson hedges are about the same as the results for the Black-Scholes hedges. The results for the delta-vega and delta-gamma neutral trading strategies are in line with the results for the delta neutral trading strategies. It appears that the delta-vega and delta-gamma strategies lead to more positive results. However, also the variability of the results is larger. The difference between the Black-Scholes and the Chen-Johnson rations turns out to be more important for the delta-vega and delta-gamma hedges than for the simple delta hedges, although this difference does not alter any conclusion.

This leads to the following conclusions. First, we do not find any serious inefficiencies in the market for DLTCs. This result is in line with results found by other researchers for other types of call options and warrants. Second, the use of delta-vega and delta-gamma neutral trading strategies leads more often to positive results, but also to more variable results, than the simple delta strategies. Therefore more research on the use of trading strategies with multiple neutral factors is necessary.

The analysis in this paper can easily be extended to more factors, such as e.g. delta-gamma-vega neutral trading strategies. In a spreading strategy, as used in this paper, in order for a trading strategy to be neutral in n factors, generally n+1 options are necessary. In case also the underlying asset is included in the trading strategy, generally only n options are necessary in order to make the trading strategy neutral in n factors.

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Table 1: Number of observations for each long term call option during each research interval

	Number of observations used in our study	
Long term call option	**April 1 to Sept. 30 1990**	**April 1 to Sept. 30 1991**
Akzo 1986	123	--
Akzo 1987	--	38
Akzo 1988	116	--
Akzo 1989	120	119
Akzo 1990	--	119
KLM 1986	123	--
KLM 1987	--	42
KLM 1988	72	--
KLM 1989	107	64
KLM 1990	--	121
Philips 1986	121	--
Philips 1987	--	104
Philips 1988	124	--
Philips 1989	120	125
Philips 1990	--	126
Royal Dutch 1986	121	--
Royal Dutch 1987	--	124
Royal Dutch 1988	118	--
Royal Dutch 1989	122	126
Royal Dutch 1990	--	105
Unilever 1986	122	--
Unilever 1987	--	109
Unilever 1988	99	--
Unilever 1989	120	118
Unilever 1990	--	84

Table 2: Results of a delta neutral trading strategy with long and short maturity call options[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		c = ƒ 1.00		c = ƒ 0.00		c = ƒ 1.00	
	1990[c]	1991	1990	1991	1990	1991	1990	1991
				Akzo				
Median	3.32	8.90	-0.29	6.73	0.00	-1.45	-4.45	-3.62
Average	6.11	362.1	0.74	347.1	2.51	576.9	-2.91	561.0
std.dev.	57.9	1321	56.9	1313	54.6	1495	54.8	1487
N	106	15	106	15	94	6	94	6
				KLM				
Median	9.49	1.81	4.87	-0.54	-3.94	-4.43	-7.95	-6.88
Average	7.05**	-2.56	2.88	-7.47	-2.58	-2.37	-6.79	-4.76
std.dev.	18.0	24.9	18.1	28.3	19.2	14.9	19.2	14.9
N	85	12	85	12	70	5	70	5
				Philips				
Median	0.00	6.30	-2.45	0.31	0.00	0.00	-5.88	-3.66
Average	2.84	11.64**	-3.51	0.40	-1.73	-7.92	-8.17	-18.44
std.dev.	28.6	41.8	28.8	41.5	29.4	40.1	29.6	42.7
N	106	84	106	84	95	67	95	67
				Royal Dutch				
Median	14.87	27.98	9.89	23.68	-2.52	-0.32	-7.34	-4.01
Average	13.09*	27.26**	8.35	23.17**	4.31	-0.11	-0.42	-14.99
std.dev.	74.5	72.8	74.5	72.9	78.1	76.0	78.1	76.0
N	107	83	107	83	97	64	97	64
				Unilever				
Median	-7.59	29.08	-12.07	24.50	-11.47	10.00	-16.17	5.20
Average	-2.75	29.33**	-7.27	24.88*	-8.32	-4.82	-12.85	-9.31
std.dev.	140.0	85.7	140.1	85.8	137.5	95.2	137.5	95.2
N	105	40	105	40	94	25	94	25

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130.Trading profits are expressed in guilders x100.

b: c indicates the one-way, per contract (=100 options) transaction costs.

c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986 and the 1989 call options series; in 1991 trading strategies are based on the 1987 and 1990 call options series.

* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Table 3: Results of a delta neutral trading strategy with long and short maturity call options, using hedge ratios as in Chen and Johnson[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		c = ƒ 1.00		c = ƒ 0.00		c = ƒ 1.00	
	1990[c]	1991	1990	1991	1990	1991	1990	1991
				Akzo				
Median	3.05	9.87	0.06	7.67	0.00	-19.87	-4.39	-22.06
Average	5.36	93.16	0.23	79.90	2.13	695.41	-3.05	678.96
std.dev.	56.1	281.7	56.2	281.1	54.3	1665	54.4	1658
N	106	13	106	13	94	5	94	5
				KLM				
Median	9.67	3.87	4.89	1.61	-3.53	-4.26	-7.81	-6.59
Average	6.68**	-2.14	2.62	-7.08	-2.79	-1.50	-6.89	-3.85
std.dev.	17.6	23.7	17.7	26.7	18.7	16.5	18.7	16.5
N	85	11	85	11	70	4	70	4
				Philips				
Median	0.00	6.36	-2.43	1.89	0.00	0.00	-5.63	-3.87
Average	2.05	10.73**	-3.82	0.18	-1.91	-7.40	-7.85	-17.24
std.dev.	26.7	40.2	27.0	40.1	28.6	38.0	28.8	40.2
N	106	83	106	83	95	66	95	66
				Royal Dutch				
Median	15.84	27.97	10.91	23.57	-2.72	-0.50	-7.84	-4.39
Average	13.39*	27.18**	8.65	23.10**	0.86	-10.86	-3.87	-14.93
std.dev.	74.3	72.5	74.3	72.6	71.2	75.8	71.2	75.8
N	102	83	102	83	92	64	92	64
				Unilever				
Median	-8.53	28.92	-13.02	24.53	-12.27	10.00	-16.76	5.22
Average	-2.73	29.18**	-7.22	24.76*	-7.71	-4.88	-12.21	-9.34
std.dev.	139.4	85.1	139.4	85.1	136.8	94.4	136.8	94.4
N	100	40	100	40	89	25	89	25

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130. Trading profits are expressed in guilders x100.
b: c indicates the one-way, per contract (=100 options) transaction costs.
c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986 and the 1989 call options series; in 1991 trading strategies are based on the 1987 and 1990 call options series.
* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Table 4: Results of a delta and vega neutral trading strategy with long, medium and short maturity call options[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		c = ƒ 1.00		c = ƒ 0.00		c = ƒ 1.00	
	1990[c]	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
				Akzo				
Median	-1.03	-17.01	-10.35	-19.88	3.74	15.93	-3.60	13.14
Average	4.72	-4.11	-3.68	-10.34	107.83	37.06	95.91	19.30
std.dev.	76.0	28.6	78.1	26.8	781.2	66.7	779.6	79.9
N	32	6	32	6	32	3	32	3
				KLM				
Median	14.78	-	9.55	-	-2.94	-	-22.44	-
Average	14.47**	-	7.67	-	14.01	-	-1.08	-
std.dev.	22.3	-	22.0	-	86.2	-	87.9	-
N	22	-	22	-	19	-	19	-
				Philips				
Median	6.61	6.55	1.47	2.77	-3.80	-0.98	-10.54	-41.08
Average	-8.17	7.83**	-33.60	1.87	-3.57	-0.51	-31.67	-38.10
std.dev.	118.4	13.2	246.4	13.5	20.6	20.2	138.0	39.2
N	45	34	45	34	41	31	41	31
				Royal Dutch				
Median	27.69	55.56	20.48	51.50	-18.35	-9.77	-26.59	-26.51
Average	28.30	258.20**	21.79	229.62**	-99.10	50.49	-106.78	37.83
std.dev.	103.0	492.9	103.2	479.0	439.3	1789	439.6	1793
N	32	29	32	29	30	34	30	34
				Unilever				
Median	-18.54	42.12	-24.76	36.58	27.52	35.57	19.89	26.24
Average	-15.72	36.43*	-22.15	30.73	74.88	36.72	68.20	29.59
std.dev.	123.7	84.2	123.5	84.2	277.3	198.2	278.5	198.4
N	9	18	9	18	8	18	8	18

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130. Trading profits are expressed in guilders x100.
b: c indicates the one-way, per contract (=100 options) transaction costs.
c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986, the 1988 and the 1989 call options series; in 1991 trading strategies are based on the 1987, the 1989 and the 1990 call options series.
* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Table 5: Results of a delta and vega neutral trading strategy with long, medium and short maturity call options, using hedge ratios as in Chen and Johnson[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		c = ƒ 1.00		c = ƒ 0.00		c = ƒ 1.00	
	1990[c]	1991	1990	1991	1990	1991	1990	1991
				Akzo				
Median	9.75	-3.56	6.54	-12.27	0.00	-16.48	-11.14	-28.40
Average	44.66**	8.95	35.76**	-0.12	125.29	-2.78	28.75	-19.32
std.dev.	103.8	37.6	100.6	37.7	565.4	31.9	802.5	39.9
N	33	3	33	3	37	3	37	3
				KLM				
Median	10.91	-	2.23	-	-3.24	-	-23.17	-
Average	13.22**	-	7.15	-	-78.84	-	-92.08	-
std.dev.	21.2	-	21.6	-	327.0	-	325.1	-
N	19	-	19	-	19	-	19	-
				Philips				
Median	6.69	-2.07	1.44	-9.47	-2.29	0.00	-9.21	-40.20
Average	3.66	0.81	-2.05	-7.19	-1674.1	20.66	-1684.8	-17.35
std.dev.	31.4	13.4	31.3	13.4	10807	85.6	10806	100.4
N	19	9	19	9	41	31	41	31
				Royal Dutch				
Median	31.37	176.80	25.22	166.09	-12.65	28.03	-21.26	23.87
Average	50.91*	245.38**	29.70	225.35**	-101.12	4923.9	-108.71	4891.1
std.dev.	117.8	3095	117.9	307.7	450.8	19982	451.2	19895
N	30	14	30	14	30	34	30	34
				Unilever				
Median	-31.01	48.23	-35.01	41.94	-25.43	34.55	-31.66	25.24
Average	-25.57	62.84**	-31.46	57.13*	-19.04	33.46	25.26	26.75
std.dev.	130.8	135.2	131.0	134.8	258.1	186.9	258.9	187.4
N	7	18	7	18	9	18	9	18

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130. Trading profits are expressed in guilders x100.
b: c indicates the one-way, per contract (=100 options) transaction costs.
c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986, the 1988 and the 1989 call options series; in 1991 trading strategies are based on the 1987, the 1989 and the 1990 call options series.
* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Table 6: Results of a delta and gamma neutral trading strategy with long, medium and short maturity call options[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		c = ƒ 1.00		c = ƒ 0.00		c = ƒ 1.00	
	1990[c]	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
				Akzo				
Median	17.82	-28.53	8.93	-33.28	2.48	-17.49	-5.23	-22.15
Average	26.75**	-15.82	20.39*	-20.66	30.64	-253.66	23.80	-261.15
std.dev.	56.0	42.4	56.2	42.2	91.6	426.9	91.6	423.9
N	22	6	22	6	19	3	19	3
				KLM				
Median	9.47	-	6.00	-	3.00	-	-3.70	-
Average	18.13*	-	8.28	-	70.78*	-	63.96	-
std.dev.	47.7	-	45.45	-	214.0	-	213.3	-
N	20	-	20	-	28	-	28	-
				Philips				
Median	2.51	6.16	-1.99	1.21	-3.39	0.00	-7.55	-8.03
Average	9.63*	7.06**	4.17	2.37	-2.23	28.60	-7.54	18.85
std.dev.	28.0	12.2	28.1	12.4	31.5	111.3	32.4	112.7
N	29	34	29	34	26	31	26	31
				Royal Dutch				
Median	15.85	62.59	8.36	51.77	-18.47	-28.38	-26.75	-35.84
Average	50.79**	59.21**	44.16*	53.23**	34.74	-95.49*	27.26	-111.25
std.dev.	130.7	72.0	130.4	71.7	347.2	216.5	347.9	220.0
N	28	19	28	19	28	15	28	15
				Unilever				
Median	-18.91	44.86	-24.94	40.65	9.08	301.12	3.59	296.46
Average	5.21	269.86	-0.95	257.75	57.39	6848.1	51.42	6824.6
std.dev.	105.9	541.9	105.2	528.7	248.8	16592	249.2	16545
N	9	3	9	3	8	6	8	6

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130. Trading profits are expressed in guilders x100.
b: c indicates the one-way, per contract (=100 options) transaction costs.
c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986, the 1988 and the 1989 call options series; in 1991 trading strategies are based on the 1987, the 1989 and the 1990 call options series.
* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Table 7: Results of a delta and gamma neutral trading strategy with long, medium and short maturity call options, using hedge ratios as in Chen and Johnson[a]

	Ex post				Ex ante			
	c = ƒ 0.00[b]		**c = ƒ 1.00**		**c = ƒ 0.00**		**c = ƒ 1.00**	
	1990[c]	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
				Akzo				
Median	16.90	-29.09	8.61	-33.73	3.87	-	-3.09	-
Average	25.75**	-8.28	19.05	-13.07	28.16	-	21.40	-
std.dev.	58.7	42.7	58.8	42.4	95.9	-	96.0	-
N	22	5	22	5	18	-	18	-
				KLM				
Median	8.74	-	5.28	-	-12.01	-	-15.46	-
Average	12.09	-	4.56	-	-16.26	-	-21.59	-
std.dev.	37.7	-	37.2	-	46.0	-	45.7	-
N	19	-	19	-	28	-	28	-
				Philips				
Median	4.77	6.10	0.48	1.35	-1.25	0.00	-5.70	-7.92
Average	7.01	6.79	1.33	2.21	-0.02	28.99	-5.47	19.42
std.dev.	25.5	11.8	25.9	12.0	30.1	110.8	30.9	112.2
N	27	34	27	34	24	31	24	31
				Royal Dutch				
Median	26.90	67.94	19.57	57.93	-17.60	-48.60	-27.23	-52.98
Average	58.25**	831.28	52.41	822.51	-66.82	-346.46	-82.15	-359.98
std.dev.	131.8	3953	132.1	3943	347.9	823.8	348.3	822.2
N	32	25	32	25	33	21	33	21
				Unilever				
Median	-25.34	-	-29.54	-	-12.72	-	-16.84	-
Average	-11.01	-	-15.81	-	15.65	-	9.66	-
std.dev.	117.7	-	117.0	-	252.9	-	252.5	-
N	7	-	7	-	10	-	10	-

a: The numbers in the table indicate the median, average and standard deviation of the trading profits in guilders, as well as the number of arbitrage possibilities, N, out of a maximum number of observations of 130. Trading profits are expressed in guilders x100.
b: c indicates the one-way, per contract (=100 options) transaction costs.
c: The years 1990 and 1991 indicate the year of observation. In 1990 trading strategies are based on the 1986, the 1988 and the 1989 call options series; in 1991 trading strategies are based on the 1987, the 1989 and the 1990 call options series.
* indicates that the average trading profit is significantly larger than zero at the 5% level; ** indicates that the average trading profit is significantly larger than zero at the 1% level.

Appendix 1: Long term call options outstanding in our research period

	Range of exercise prices during the research period		Introduction month [a]	Scheduled expiration date [a]
Akzo 1986	*f* 150		October 1986	18-10-91
Akzo 1987	*f* 180		October 1987	16-10-92
Akzo 1988	*f* 150		October 1988	15-10-93
Akzo 1989	*f* 135		October 1989	21-10-94
Akzo 1990	*f* 80		October 1990	17-10-95
KLM 1986	*f* 40		January 1987	18-10-91
KLM 1987	*f* 55		October 1987	16-10-92
KLM 1988	*f* 35		October 1988	15-10-93
KLM 1989	*f* 50		October 1989	21-10-94
KLM 1990	*f* 20		October 1990	17-10-95
Philips 1986	*f* 55		October 1986	18-10-91
Philips 1987	*f* 55		October 1987	16-10-92
Philips 1988	*f* 30		October 1988	15-10-93
Philips 1989	*f* 45		October 1989	21-10-94
Philips 1990	*f* 20		October 1990	17-10-95
Royal Dutch 1986	*f* 210	- *f* 105	October 1986	18-10-91
Royal Dutch 1987	*f* 270	- *f* 135	October 1987	16-10-92
Royal Dutch 1988	*f* 115		October 1988	15-10-93
Royal Dutch 1989	*f* 145		October 1989	21-10-94
Royal Dutch 1990	*f* 135		October 1990	17-10-95
Unilever 1986	*f* 500	- *f* 100	October 1986	18-10-91
Unilever 1987	*f* 140		October 1987	16-10-92
Unilever 1988	*f* 120		October 1988	15-10-93
Unilever 1989	*f* 150		October 1989	21-10-94
Unilever 1990	*f* 145		October 1990	17-10-95

[a] = source: European Options Exchange